

Technical Memorandum

U. S. NAVY TEST PROGRAM FOR AN ARINC 599
OMEGA NAVIGATION SYSTEM

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Antisubmarine Aircraft Test Directorate

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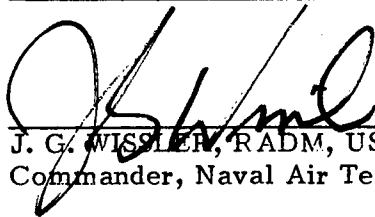
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PREFACE

This Technical Memorandum was prepared for presentation at the Fifth Annual Meeting of the International Omega Association 5-7 August 1980 at Bergen, Norway. The subject material derives from AIRTASKS under which NAVAIRTESTCEN investigated application of commercially available Omega Navigation Systems to selected Navy aircraft. The Omega system evaluated was the LTN-211 which is designed for conformance to prevailing commercial practice. Candidate using aircraft included the A-3B and P-3 airplanes. Aircraft and mission requirements unique to these installations are presented. Tests devised to determine compliance of the LTN-211 which these requirements are described with preliminary test results included. Final test results will be contained in formal NAVAIRTESTCEN reports which will be released under applicable AIRTASK directives.

APPROVED FOR RELEASE

A handwritten signature in dark ink, appearing to read 'J. G. Wissler', is written over a horizontal line.

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BACKGROUND

The initial and primary sponsor of development of the Omega Navigation System (ONS) was the United States Navy. While the system was originally conceived as a navigation aid for marine vessels on the high seas, potential for aircraft utilization of Omega signals as a navigational aid was also recognized. Early demonstrations of airborne Omega tracking and positioning were carried out by the Naval Research Laboratory (NRL), culminating in the "Mark III" receiver that was demonstrated on a transatlantic flight in 1968 (Eisenberg and Williams, 1969).

Success of the NRL experiments encouraged the Navy to develop the first operationally practical airborne ONS, which was designated the AN/ARN-99. Technical flight evaluation of the prototype ARN-99 system was completed at the Naval Air Test Center (NAVAIRTESTCEN), Patuxent River, Maryland, in 1971 (Sakran, 1971). While the ARN-99 does not physically resemble current equipments, design precedents were established that have been duplicated by virtually all airborne ONS's since. These features include:

- a. Partitioning of the system into three line replacement units; Antenna-Coupler Unit (ACU), Receiver-Processor Unit (RPU), and Control-Display Unit (CDU).
- b. Preferred use of orthogonal loop (H-field sensitive) elements as receiving antennas in order to minimize susceptibility to precipitation static interference.
- c. Automatic synchronization of the receiver timing cycle to the Omega transmission format.
- d. Maximum use of digital processing techniques for signal phase tracking, navigation, and steering functions.
- e. Simultaneous tracking of the three primary Omega frequencies for lane ambiguity monitoring and resolution.
- f. Automatic coordinate conversion for initialization and subsequent navigation in geodetic latitude/longitude coordinates, vice hyperbolic lines of position.
- g. Use of aircraft sensor measurements of true airspeed (TAS) and magnetic heading (with software-provided magnetic variation values) for dead reckoning between Omega measurements and phase tracker rate aiding.
- h. A human-engineered, user-prompting CDU for interface with the operator.

The ARN-99 subsequently entered production in two forms. The ARN-99(V)2 and ARN-99(V)4 configurations are each complete stand-alone navigation systems, differing primarily in the amount of excess computer memory available for non-Omega tasks. The ARN-99(V)1 comprises the ACU and only the receiver/phase comparator portion of the RPU. It is used in applications wherein Omega signal tracking and navigation software functions are implemented in large, general purpose digital processors integral to certain aircraft systems.

Several ONS designs are currently in operational use by the U.S. Navy. These include the following:

- a. The ARN-99(V)1 is in the P-3B and P-3C airplanes, used in conjunction with the AN/ASN-124 and CP-901 central computers, respectively.
- b. ARN-99(V)2/4 systems are operational in the C-9B, EC-130Q, and the US-3A.

c. The AN/ARN-131 ONS, the result of the U.S. Air Force Omega 2041 program, is being retrofitted into the Navy C-2A fleet.

d. The CMA-734, with its VLF receiver option, is included in UC-12B airplanes designated for overseas deployment.

Simultaneously with increased use of ONS, the commercial airlines were recognizing the utility of Omega as a replacement for LORAN-A and/or a very cost-effective alternative to inertial systems. Advances in component technology and a competitive marketplace resulted in systems which promise to meet and/or exceed performance of the original ARN-99, but at sharply reduced cost. The ARINC 580 and 599 characteristics, along with the RTCA DO-160 and DO-164 standards, serve to define form, fit, function, and minimum performance parameters of new ONS designs. Since, for several years, commercial grade inertial navigation systems (INS's) designed to similar documented requirements have been successfully used in certain military aircraft, there was reason to believe that ARINC 580 or 599 compatible ONS equipments would be similarly effective. Obviously, such applications must be limited to aircraft missions wherein the equipment environment does not induce significantly greater stress than in commercial airline service. To date, NAVAIRTESTCEN has verified operation of a commercially available ONS in two types of aircraft, the A-3B and P-3B.

SOURCE SELECTION

At the time of source selection for the initial A-3B tests, there were at least six manufacturers advertising Omega systems in the U.S. market. Since the Navy did not have funds committed for ONS research and development efforts, sufficient qualification criteria were placed on perspective offerors to limit candidate systems to those having already demonstrated acceptable performance in commercial service. Thus, the ONS furnished for test must:

a. Comply with ARINC characteristic 599 for the Mark 2 ONS.

b. Have received an FAA engineering Supplemental Type Certification for nonhazard installation and airworthiness of the ONS on at least one aircraft type of a commercial air carrier per FAA Advisory Circular No. 120-31A or equivalent.

c. Have received FAA Operational Approval certifying its flight worthiness including satisfactory training and maintenance techniques on at least one commercial airline per FAA Advisory Circulars No.'s 120-31A and/or 120-33 or equivalent.

d. Comply with FAA Technical Standard Orders C94 requiring satisfactory completion of all design inspections and tests enumerated in RTCA Document DO-164, Sections 3 and 4, and Appendix A, Part IV, conducted under environmental conditions as specified in applicable sections of RTCA DO-160 for Class Y aircraft.

e. Document at least 100,000 flight hours of actual experience in commercial aircraft recorded over the preceding 12-month period.

f. Have exhibited during cumulative actual commercial aircraft use, a system reliability equal to or greater than 1500 hours mean time between failures.

g. Implement use of the Navy VLF communications station signals as back-up to the Omega navigation signals with appropriate annunciation of VLF use.

DESCRIPTION OF ONS

The ONS selected for flight tests was the LTN-211 manufactured by Aero Products Division, Litton Systems, Incorporated, of Canoga Park, California. The system as tested conforms to ARINC Characteristic 599 in all significant respects except that the ACU is the optional "brick" configuration; i.e., without a streamlined shroud. This more compact ACU fits in the tail cone area of the A-3B airplane. The LTN-211 estimates geodetic position and internal clock bias by means of a weighted least squares filter which receives independent measurements of phase on each frequency from a maximum of seven of the eight Omega stations. Circular "multi-rho" LOP geometry is used, and Omega phase measurements are adjusted by a software implementation of the ONSOD propagation prediction model.

The LTN-211 includes four TRF receivers each having two stages of mechanical filter bandwidth limiting. It is a microprocessor based system using ultraviolet erasable read-only semi-conductor program memory. The software provided for Navy test began as a standard commercial program, differing only in the indexing constant applied to the A-3B TAS synchro input. To date, the software has undergone four minor modifications. These were necessary to adapt the LTN-211 to various additional Navy airspeed sensors, enlarge its range of aircraft compatibility, and to provide greater versatility in adapting it to differing missions. All capabilities remain resident in a single common Navy software, selectable by means of pin discretes during installation.

The LTN-211 configuration selected for test includes the VLF receiver option, which consists of a software-tunable receiver circuit board fitting within the RPU and requiring expanded computer memory and software. In this configuration, Omega phase measurements on 10.2, 11.3, and 13.6 kHz are supplemented by measurement of phase displacements of a selected group of four out of nine VLF communications transmissions. The VLF signals are processed by the receiver channel normally devoted to the 11.05 kHz Omega signals.

DESCRIPTION OF AIRCRAFT AND ONS INSTALLATIONS

The Douglas A-3 "Skywarrior" is a twin-engine jet, swept wing transonic carrier-based airplane, originally designed for the medium range heavy attack mission. The airplane entered service in 1956. Subsequent modifications have resulted in its use for electronic intelligence, tactical electronic warfare, VIP transport, and aerial refueling missions. Currently, the A-3 fleet exists in four versions: EA-3B, ERA-3B, TA-3B, and KA-3B. The airplane available for Omega tests was a KA-3B, the aerial refueling version. The ONS installation consisted of an ACU mounted in the fuselage tail cap, a CDU normally mounted at the Bombardier/Navigator (B/N) station (in front of the right-hand seat), and the RPU mounted on the equipment platform behind the B/N seat with the RPU long dimension oriented fore-aft. The installation was designed for integrity during carrier operation. A TAS computer presently in Navy inventory and previously used in other A-3 systems was installed as part of the ONS retrofit in order to automatically supply a TAS input to the ONS. Magnetic heading was taken from the existing MA-1 gyromagnetic compass system. For many of the flight tests, the CDU was temporarily relocated by use of an extension cable to the third seat directly behind the pilot. This freed the two front seats from the ONS data logging workload and allowed full time ONS monitoring by a dedicated technical observer. However, for carrier suitability trials, electromagnetic interference tests, mission suitability, and crew interface evaluations tests, the CDU was mounted in its permanent position.

The Lockheed P-3 "Orion" is a four-engine, turboprop subsonic land-based airplane. A derivative of the Lockheed Electra, it is designed for overwater patrol missions and includes diverse sensors for detection, identification, and tracking of submarine and surface vessels. The airplane is capable of extended duration flight during which its inertial and Doppler radar navigation systems may accumulate excessive error if not monitored by external

position fixes. The P-3 fleet includes P-3A, P-3B, and P-3C types, each with differing avionics configurations. As noted previously, some P-3B and P-3C configurations include the ARN-99(V)1 Omega receiver, a central computer for data processing and a multifunction display system. Thus, in these airplanes, reliability of Omega position fixing is dependent on a complex integrated system. Isolating the Omega functions in a stand-alone system, such as the LTN-211, will increase ONS reliability and remove a significant computational burden from the central mission computer. The airplane used for these ONS tests was the prototype "Modernized" P-3B. The LTN-211 ACU was mounted on the bottom centerline near the tail, separated from the existing ARN-99 ACU by a distance of one meter. The CDU was installed at the navigator's station adjacent to the existing ARINC 561 INS CDU, and the RPU was mounted in an equipment bay behind the navigator's seat. TAS and heading data were derived from existing sources.

Both the KA-3B and the P-3B ACU locations were selected on the basis of detailed noise skin maps and prior Omega experience with these aircraft.

SCOPE OF TESTS

Throughout this effort, emphasis has been placed on testing the interface of the ONS with the specific type aircraft, rather than on internal aspects of ONS performance. Aircraft interfacing includes antenna location, electromagnetic compatibility (EMC) with existing aircraft systems, interconnection with rate aiding sensors (airspeed and heading), and carrier suitability where applicable. These aspects require independent verification in each type aircraft considered for ONS installation. Suitability of the ONS CDU with crew station environment and compatibility with aircraft mission requirements were also considered.

Internal ONS performance criteria such as signal tracking, station selection, and estimation of navigation parameters were exercised by laboratory simulation at the Naval Ocean Systems Center (NOSC) over a wide range of conditions. In-flight measurement of these functions would more aptly be the subject of a formal technical evaluation and would require use of precision ground tracking radar (or equivalent), dedicated onboard instrumentation, and flights over a wide range of geographic locations. In the case of an ONS already certified in commercial airline service, it was assumed that internal aspects of ONS design have already been proven via compliance with ARINC 599, RTCA DO-164, and FAA certification procedures. Specifically, it was assumed that the ONS navigational accuracy would be commensurate with the propagation prediction accuracy of the ONSOD model if it could be proven that signals were indeed being received and properly used.

It was thus decided that ONS data would be recorded manually from the CDU displays and that ground radar services would not be used for precision aircraft positioning. A portable battery operated cassette magnetic tape recorder was supplied by Litton to continuously log data available to the CDU. This unit was flown as a precautionary measure in case unexpected ONS problems developed.

NOSC TESTS

Augmenting the NAVAIRTESTCEN flight tests, the LTN-211 was subjected to laboratory flight simulations using the signal simulator in custody of NOSC, San Diego. The flight simulator served to exercise the system under a variety of geographic, dynamic, and signal conditions and provided useful insight into the ONS mechanization and capabilities.

The world-wide NOSC simulation capability is germane to U.S. Navy requirements since Navy aircraft fly daily over all the world's oceans and are also called upon to support scientific missions at both poles. Future military requirements cannot be limited within a priori geographic bounds. Since actual flight verification of the ONS's behavior over the entire earth is clearly impractical, simulation provided a viable alternative.

Two significant changes in the LTN-211 software were implemented as a result of NOSC tests. The first raised the signal quality (phase variance) threshold value for acceptance of a phase measurement by the navigational least squares filter. The original threshold (12 on the CDU display range of 0 to 40) allowed occasional erroneous phase measurements, possibly the result of receiver filter ringing, to masquerade as valid signals and impact the navigation solution. Since measurement inputs to the LTN-211's least squares filter are weighted proportional to signal quality index, these false but low quality measurements normally have little effect on the filter's estimates of position and clock bias. However, in the event of operation in a marginal signal reception region, wherein the third strongest station approaches the programmed acceptance threshold, the filter's estimates become noisy and subject to error. Should the ONS subsequently degrade to the two-station rho-rho mode, a large position error offset and drift rate would result from the residual position and clock bias errors. The system is now being flown with the signal threshold value programmed at 13 vice 12.

The other major software change corrected a latitude numerical divergence uncovered during simulated polar flight.

NAVAIR TESTCEN TESTS

General

At the time of this writing, the KA-3B flight data is undergoing analysis and final test results are not yet released. The P-3B flight tests are continuing. A synopsis of the tests performed and pertinent results noted to date follows, with emphasis on those aspects peculiar to the Navy applications.

Airworthiness

Installations in both airplanes were inspected for structural integrity, safety of electrical wiring, and measurement of ambient temperatures at the RPU location. No problems inherent to the LTN-211 have been reported.

Reliability of the ONS has been good. To date there has been one overt ONS malfunction; an intermittent CDU "lock-up" and "operator error" annunciation in the KA-3B. This occurred on two successive flights but has not been duplicated since. Another malfunction resulted from an installation oversight: the screw-on collar attaching the signal cable connector at the ACU was not originally safety wired in the KA-3B. After several flights, the connector disengaged causing loss of signal reception. From this experience we learned two lessons:

a. The ACU connector must not be secured by electrically conductive safety wire attached to the airframe structure. With this ACU, electrical continuity between the connector shell and airframe completes ground loops, resulting in sufficient noise induction into the ACU cable to obviate synchronization. Since the ACU is in a location inaccessible for frequent inspection, it is necessary to insure mechanical security of the ACU connector, but without using conductive safety wire in the usual manner. Several alternatives are under study.

b. The LTN-211 built-in-test (BIT) for the ACU injects a test/calibration signal into the ACU during the time segments in which the most distant Omega station is transmitting. Thus, the ONS must first synchronize to the Omega transmission format before ACU BIT can be initiated. However, as synchronization is impossible if the ACU is nonfunctional or if the airplane is in an area of excessive electrical noise, the present BIT is not totally effective for preflight checkout of the ACU. Since degraded signal reception has been observed with the KA-3B parked adjacent to other active aircraft (indicating an elevated

noise level), there is special concern over the ability of the system to synchronize and thus initiate ACU BIT when on a crowded carrier deck. The manufacturer is investigating alternate ACU test techniques to overcome this limitation. In fairness to the LTN-211, however, NAVAIRTESTCEN experience with other ONS suggests that a universally effective ACU BIT remains a challenge to many designers.

Another question concerning airworthiness arises when the ONS is not installed in the aircraft. Because of logistics considerations, an ONS equipped Navy aircraft may fly without the ONS RPU physically installed. Without the RPU installed, the ACU signal cable is unterminated and the cable and ACU are isolated from airframe ground. In the event of lightning strike or triboelectric charging near the ACU, hazardous voltage potentials could be present at the free cable end inside the aircraft. When the identical situation arose during ARN-99 development, it was decided to mount an electrically grounded connector near the RPU rack as an alternate termination for the ACU cable whenever the RPU is physically removed. A similar provision for LTN-211 installations in Navy aircraft has been recommended.

Aircraft Interfacing

Aircraft interfaces include primary electrical power, TAS and heading rate aid inputs, oleo strut discrete signal, and ONS outputs to flight instruments.

The electrical power systems in the KA-3B and P-3B are dissimilar. The P-3 electrical generators are directly coupled to constant speed engines. Thus, power is well regulated in voltage and frequency, remaining near 397 Hz, which is an ideal frequency considering harmonic interference to the Omega signals. KA-3B ac power is produced by generators driven by air turbine motors which are supplied engine bleed air. Power normally varies over wide ranges in voltage and frequency. The LTN-211's narrow-band hardware filtering probably contributed to successful Omega reception in the KA-3B. Transient voltage sags during takeoffs and some flight maneuvers caused the ONS to shut down and automatically reinitialize.

Heading synchro and weight-on-wheels (oleo strut switch) discrete signals were readily available in both airplanes. The ARINC 599 provision for separate synchro reference phases for heading and airspeed, each independent of ac primary power phase, made these interfaces relatively straightforward. As noted previously, a TAS computer was installed in the KA-3B concurrent with the ONS. Neither airplane's TAS system was compatible with commercial standards, requiring modifications in the TAS input and TAS program pin logic portions of the LTN-211 software.

In neither the KA-3B nor P-3B installation is the ONS coupled to the autopilot. In the KA-3B, ONS steering was displayed on the ID-249 course deviation indicator (CDI) lateral bar. An ONS capability for driving both bearing pointers (drift angle and desired track) of an ID-663C/U bearing distance heading indicator (BDHI) was demonstrated. However, pilot reaction, although favorable to the ONS BDHI display format, was unfavorable when it became evident that low-frequency ADF and VOR bearing displays would have to be switched out in order to substitute Omega. Since there was not room on the cockpit panel to add an additional instrument, the already cumbersome display switching of the KA-3B would have had to be made even more complicated to accommodate ONS. These considerations resulted in unanimous pilot opinion that Omega displays should be limited to CDI, and of course the ONS CDU, presentations. Apparently VOR, TACAN, and ADF needles, even when in the search mode, provide reassurance to the pilot over the ocean. The BDHI drive capability remains in the ONS for possible future use in other installations.

EMC

In accordance with NAVAIRTESTCEN policy, installations were subjected to a brief, but formally structured, EMC "Safety of Flight Test" (SOFT) before the first flight with the

ONS. Purpose of the SOFT was to uncover any potentially hazardous conditions wherein the ONS interfered with any of the standard flight instruments or mission essential systems already in the airplane. SOFT does not address interference entering the ONS as a victim.

Detailed EMC tests have been completed on the KA-3B in the NAVAIRTESTCEN electromagnetically shielded test hangar, checking for interactions between the ONS and all other aircraft electrical and electronic systems. Controlled flight tests were also conducted to search for ONS reception interference from existing aircraft systems, with particular attention to systems which in the past have been noted to be potential Omega offenders, such as TACAN, VOR, weather and search radars, and HF transmitters.

Tests involving precipitation static susceptibility are difficult to control since atmospheric conditions cannot be scheduled on demand. Several KA-3B flights have been under conditions of light to moderate icing or where cockpit canopy streamer and corona discharge were evident. ONS performance was not significantly degraded.

A potential EMC situation peculiar to military operations exists during aerial refueling: the second aircraft flying in close proximity radiates additional interfering energy into the ONS antenna. Furthermore, equalization of electrical charges at link-up induces transient spikes on unshielded power and signal lines, thereby causing susceptible digital circuits to malfunction. Aerial refuelings with the KA-3B did not affect LTN-211 operation.

Carrier Suitability

ONS operation in a carrier based airplane such as the KA-3B poses special requirements. Foremost is mechanical integrity as the airplane is catapulted off the carrier deck and subsequently recovered aboard ship with tailhook and cable. To insure that the KA-3B installation was carrier suitable, another unique NAVAIRTESTCEN capability was employed. A model C-7 catapult and MK-7 MOD 3 arresting gear are operational at NAVAIRTESTCEN, exactly duplicating facilities on the aircraft carriers. The KA-3B was subjected to 7 catapult launches and 12 arrestments which simulated the expected range of launch/recovery situations aboard ship.

Initialization of the ONS for a carrier launched flight also poses problems. First, the electromagnetic environment of a carrier flight deck is not benign. Not only are there power circuits at both 60 and 400 Hz throughout the ship, but also broad and narrow band emitters covering the entire radio frequency spectrum. The combined noise environment has precluded reliable synchronization in some previous ONS installations. A second difficulty is the uncertainty in the carrier's geodetic position for ONS initialization. The ship is constantly maneuvering and not only is its own navigation system subject to error but delays exist in relaying position data from the ship to the aircraft ONS. Lastly, the ONS cannot depend on reliable dead reckoning to update its position as the aircraft awaits launch. The aircraft heading sensors are grossly erroneous due to magnetic deviation of the ship and/or the airplane's wings being folded with the magnetic compass sensor inverted. The aircraft TAS sensor is inoperative at carrier cruise speed. Manual inputs of heading and speed can of course be entered, but the heading input must be a compromise between ship's course (to satisfy dead reckoning) and aircraft heading (to enable loop antenna steering functions). Since aircraft heading while waiting on deck is arbitrary relative to ship's course, a satisfactory compromise is not probable.

Several software tricks have been suggested to ease the shipboard ONS initialization problems. In the interest of minimizing development of specialized software, however, it was decided to essentially ignore the problems and instead concentrate on verification of airborne ONS initialization. This tactic calls for the operator to manually reinitialize the ONS immediately after takeoff so that synchronization is accomplished away from potential interference from the ship. To be successful, ONS synchronization and signal acquisition time must be sufficiently fast such that dead reckoning error, when combined with initial position error, does not exceed the ONS's position correction, or lane ambiguity resolution, capabilities. Accordingly, most of the KA-3B test flights were conducted by initializing the

ONS following takeoff and with various offsets in initial position. Early attempts to exercise the LTN-211 in this manner yielded our first significant finding: the ONS did not attempt to correct position or obvious mislanings. The problem was soon traced to a software compilation oversight unique to the Navy system, which was corrected by Litton. All subsequent lane ambiguity resolution attempts have been successful.

Signal Acquisition and Tracking

Synchronization and signal acquisition tasks were timed for both ground and flight conditions. ONS maintenance of correct synchronization was monitored, particularly on P-3 flights which are typically 10 but which can exceed 14 hours in duration. It was felt necessary to verify that the ONS internal clock remains free of drift and transient disturbances under the stresses of flight.

Various flight profiles were explored to insure continuous phase tracking and position keeping under conditions of horizontal maneuvers intended to maximize the rate of change of received signal phase and to maximize phase acceleration. Prolonged maneuvering flight within a limited geographic area is typical of the P-3's mission. Not only do the horizontal accelerations affect ONS phase tracking and crystal oscillator stability, but the attendant high bank angles degrade ONS antenna gain. Vertical climb maneuvers, during which the ONS must track changing real world winds, were also explored.

Using the CDU indications of signal quality (estimated phase variance), reception quality as a function of station relative bearing (antenna pattern) was investigated. This test was flown simultaneously with an investigation of stability of ONS indicated wind by flying a multiheading cloverleaf pattern and plotting deviations from average displayed signal quality and average wind vector versus heading. The KA-3B antenna pattern was of concern due to the placement of the ACU at the airplane extremity.

Laboratory measurements of phase linearity as a function of signal amplitude were supplemented by overflight of various radio emitters, including the North Dakota Omega station and the Navy VLF communications transmitters NAA at Cutler, Maine, and NSS at Annapolis, Maryland. Suppression of Omega signals occurred in the vicinity of the VLF transmitters, and the ONS was unable to synchronize when near the Cutler transmitter complex. This effect may be germane since the P-3B's are operationally based at Barber's Point, Hawaii, adjacent to the 600 kW VLF communications transmitter NPM at Lualualei. Although no problems have been reported by commercial operators at Honolulu International Airport, NAS Barber's Point is closer to NPM. An on-site assessment is obviously called for!

Navigation Accuracy

There were not sufficient resources to conduct a complete test of ONS positioning accuracy. Indeed, the purpose of relying on a proven commercial system was to obviate the need for such tests. Sufficient flight test data were obtained, however, to ascertain that the LTN-211 in the KA-3B was receiving enough Omega signal information to navigate within its expected limits.

The circular error probable (CEP), defined as the population 50th percentile value of circular (radial) position error, was selected as the test demonstration criteria because of its robustness under various test conditions and because a reasonably confident estimate of its value (in the statistical sense) can be attained with a modest quantity of test data. The ARINC 599 specification for accuracy is 7 nmi accuracy at the 95th percentile level. By assuming an approximately Rayleigh statistical probability distribution for radial position error, a goal of 3 nmi CEP was adopted.

Actual aircraft position was estimated by visual mark-on-tops at low level (3,000 feet above terrain) over identifiable landmarks of known surveyed location, such as navigation aids and other radio towers. Although visual "on-top" position references are not precise, sighting accuracy has proven more than sufficient to verify the 3 nmi CEP goal. A

recognized disadvantage of using visual position references is the limited opportunity for data during hours of full darkness. Some data were taken during local sunset transition and twilight hours.

Routes traversed by the KA-3B are shown in figure 1. Although limited to within CONUS by nontechnical exigencies, the flights did include the following salient features:

- a. Coverage of both longitude extremes of CONUS, along with extensive range of latitude.
- b. Overflight of Omega, communications, and experimental VLF transmitting sites. These overflights provided opportunity to explore signal suppression due to intense fields and software rejection of navigational signals contaminated by modal interference.
- c. Overflight of other RF emitters ranging in frequency from LF LORAN-C stations to beyond UHF.
- d. Ground tracks aligned due true north-south and east-west.
- e. Flight along the Omega North Dakota - Japan baseline extension, deep in the legendary "Winnipeg Hole," a region identified as posing Omega coverage deficiencies (Swanson et al., 1978).

The temporary Omega station at Trinidad was manually deselected during all tests. Furthermore, at least one additional Omega station, dominant in the particular test area, was manually deselected during most flights. The majority of flights were made with normal use of VLF communications signals allowed, but sufficient data were obtained under pure Omega only conditions to verify the LTN-211's navigational capability should the communications signals not be usable.

The set's VLF-only (no Omega) and rho-rho (two station reception) position tracking back-up modes were exercised, as was the TAS/compass dead reckoning algorithm.

Frequent in-air restarts, intentional position offsets (entered as a "non-precision" update), and lane ambiguity resolution routine call-ups were made throughout the test program. While this is not the way the system will be used operationally, these exercises were intended to verify capability of position correction after launch from an aircraft carrier.

Figure 2 graphs the cumulative distribution function (CDF) of the KA-3B flight data sample. The CDF shown is of 391 samples of radial error in the LTN-211 indicated position. This sample included 25 flights totaling 66 flight hours. The sample shown excludes 33 points logged at times the ONS was in a degraded mode, as evidenced by the AMB, VLF, or DR annunciators being lit. The majority of degraded mode operation was intentional, caused by deliberate false position initializations or updates, or manual deselection of multiple Omega stations.

The CDF has been plotted on a nonlinear grid, distorted such that CDF's conforming to a Weibull probability distribution graph as a straight line. The Weibull distribution has been noted to fit experimental samples of ONS radial position error (Sakran, 1975). The present LTN-211 sample exhibits remarkable conformity to the Weibull CDF to at least the 99th percentile, as shown by the closeness of the experimental sample points to the fitted straight line on figure 2. One suspects that, at least, the data are self-consistent. The Weibull shape factor (slope) for this sample is 1.53, yielding somewhat greater dispersion than that expected of a zero-mean equal-variance bivariate normal (Rayleigh) CDF. (The Rayleigh CDF is a special case of a Weibull having a shape factor equal to 2.0.) The sample median yields a CEP estimate of 1.5 nmi, well under the 3 nmi demonstration goal. The fitted Weibull CDF projects a 95th percentile estimate of 4.1 nmi, which satisfies the ARINC 599 specification.

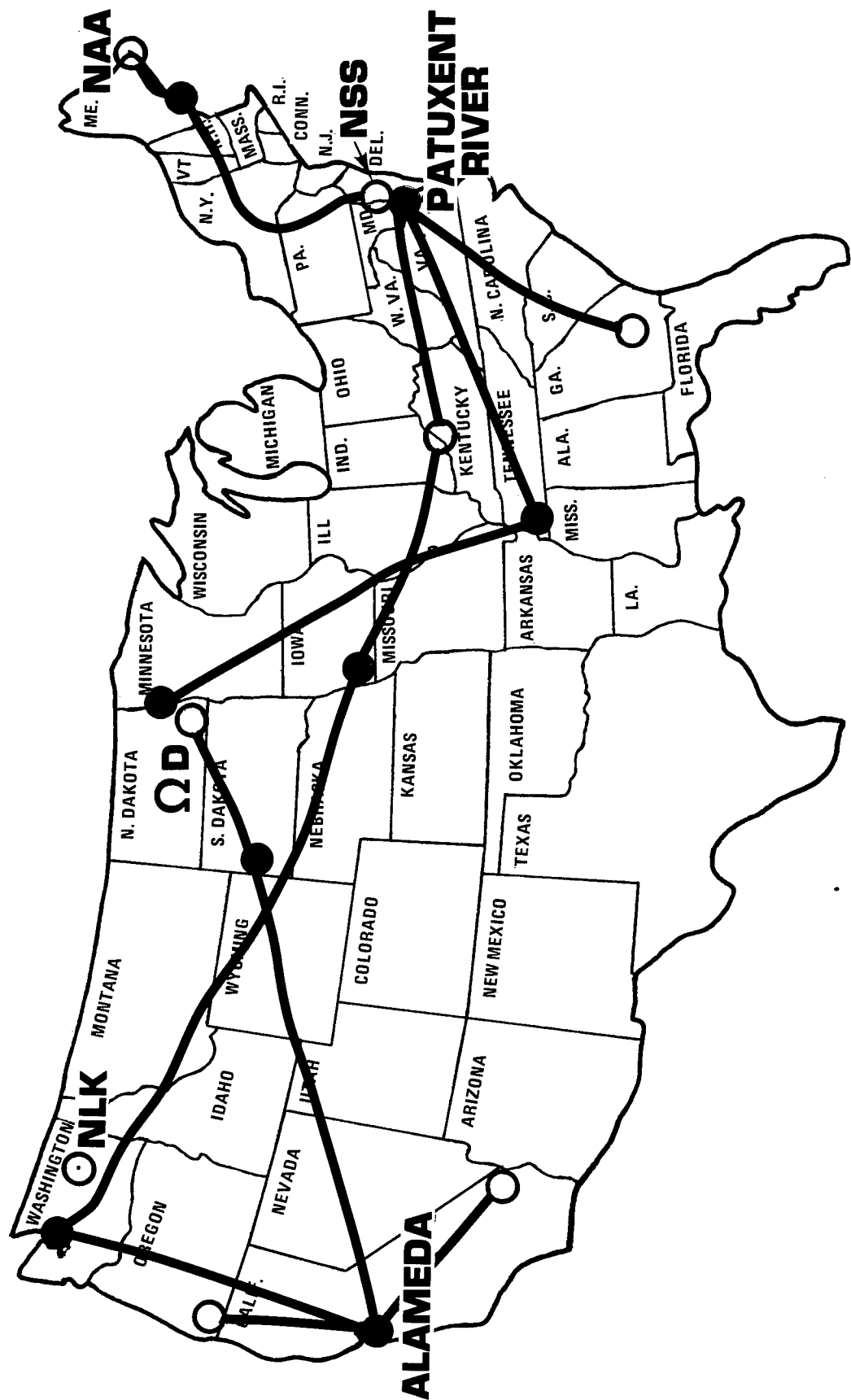


Figure 1
KA-3B LTN-211 Flights

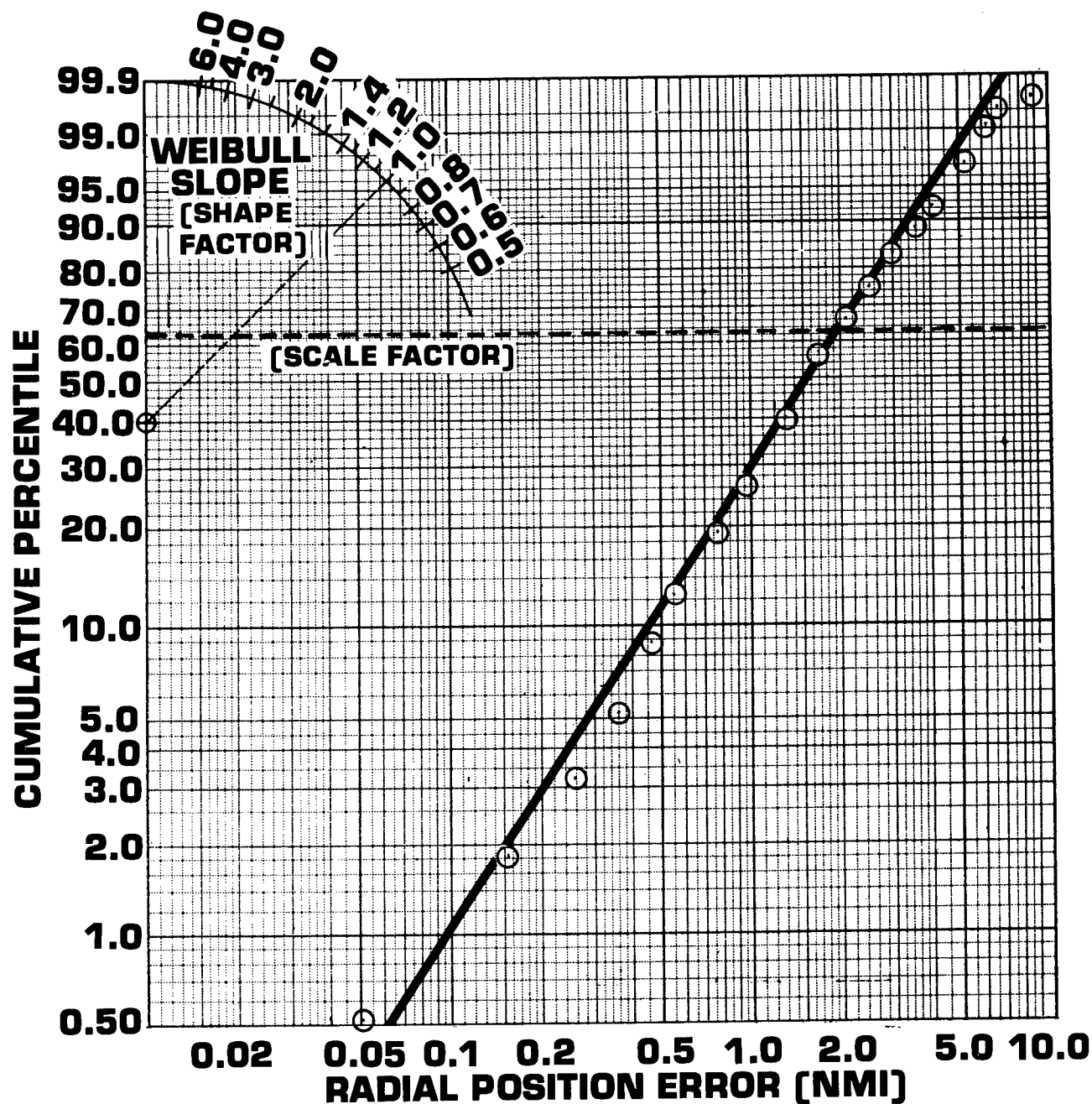


Figure 2
Fit of KA-3B Flight Sample of LTN-211 Omega/VLF Navigation System
Radial Error to the Weibull Probability Distribution

The Weibull Cumulative Distribution Function of Radial Error $R > 0$ is:

$$\text{CDF}(R) = 1 - \text{EXP}(-(R/B)^C), \text{ where } B > 0, C > 0$$

For the KA-3B sample of 341 points the scale factor $B = 2.00$ nmi and the shape factor $C = 1.53$.

CONCLUSION

Following initial exploration and development of airborne Omega navigation techniques by the U.S. Navy, ONS hardware and software designs have been refined as the result of increasing use of Omega by the airlines. The LTN-211 ONS, an example of the current generation equipment engineered in conformity to the ARINC 599 characteristic, has been investigated by the Navy for use in A-3B and P-3B aircraft. NAVAIRTESTCEN flight evaluations augmented by NOSC laboratory flight simulations are verifying that the LTN-211 satisfies the long-range overwater mission requirements and installation constraints peculiar to Naval aviation. Final reports on these evaluations will be issued by NAVAIRTESTCEN.

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